United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.447/10
20 December 1985

ENGLISH

Expert Group Meeting on Timber Construction
Vienna, Austria, 2 - 6 December 1985

TIMBER BRIDGES

FOR

DEVELOPING COUNTRIES *

Prepared by

H. J. Markerink **

* The views expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing. Mention of firm names and commercial products does not imply endorsement by the United Nations Industrial Development Organization (UNIDO).

** Civil Engineer, Hout Handel v/h, T. C. Groot, the Netherlands.

V.85-37733

CONTENTS

		Page
I.	Introduction	1
II.	Present day bridge building in Azobé	2
	A. Type 1 bridge	3
	B. Type 2 bridge	3
	C. Type 3 bridge	5
	D. Type 4 bridge	5
	E. Type 5 bridge	6
	F. Type 6 bridge	7
	G. Type 7 bridge	8
	H. The parapets and the walking deck	10
	I. Foundations	11
III.	Timber bridge constructions for developing countries	12
	A. Checklist for field research	12
	B. Preliminary design requirements	14
	C. Design of the superstructure	16
	D. Design of foundations and abutments	21
	E. Erection plans concerning superstructures	24
	F. Erection plans concerning substructures	26
IV.	Cost calculation of hardwood bridges	27

I. INTRODUCTION

Before beginning to discuss the subject "timber bridge constructions for developing countries", it is necessary to give a brief introduction about the activities of the company "Groot" which is established in Lemmer, the Netherlands.

Groot which has been an important name in hardwood industries, has forest concessions in Cameroon, Africa, from where it obtains the logs of the timber species Azobé (also called Ekki or Bongossi). The timber is partly sawn in Cameroon. This is the timber used for e.g. sheet piling. The rest of the round logs is shipped to Lemmer where the firm has a sawing mill and a factory to produce all kinds of products. These products can be categorized as follows:

1. Loose timber parts - planks for sheet piling, piles for foundations, fenders, cranemats etc.
2. Timber parts for bridge building.

Azobé is practically the only timber sort which is used by Groot. Other sorts which are rarely used are:

Basralocus - for substructures
Bilinga - for handrails and deckplanks
Iroko - for parapets
Bangkirai - for all purposes

The firm does not only produce timber parts for bridge building, but also constructs the bridges itself. These bridges are designed by "Groot Consultants", the designing department of the firm which consists of seven engineers. Its functions are:

- cost calculations
- design
- project management
- research and development

As a result of the organizing described above, the company which originally started as a hardwood merchant, has been within the last twenty years and still is one of the leaders in developing and promoting hardwood constructions, especially bridges and roof constructions.

80% of the constructions which were realized were pedestrian bridges, 15% were traffic bridges with loadings up to 60 ton vehicles and 5% were roof constructions.

The market of Groot is equally shared between the Netherlands, England and West Germany. United States, Denmark, Belgium and France are new markets where the first projects have been realized recently.

II. PRESENT DAY BRIDGE BUILDING IN AZOBE

The designed and realized bridges can be divided into seven main types of superstructures:

Type 1 - a massive beam construction, with spans up to 10 m.
Type 2 - a laminated beam. The layers are put together with steel pin dowels. Spans up to 25 m.
Type 3 - a "vierendeel" beam, with spans up to 25 m.
Type 4 - a sandwich panel construction, with spans up to 10 m.
Type 5 - the 2 and 3 pin arch construction with spans up to 35-40 m.
Type 6 - the truss-girder, with spans up to 35 m.
Type 7 - the cable-stayed bridge, with spans up to 100 m.

The substructures as well as the superstructures were designed by Groot Consultants.

A detailed analysis of the main construction of the superstructure of the seven bridge types mentioned above is presented below. This is important in reflecting the present day concept of Azobé bridge designing (at this stage, side conditions such as parapet details or load specifications are not taken into consideration).

A - Type 1

By a Type 1 bridge we mean a bridge with massive mainbeams. They are sawn out of a log outside the heart. As the Azobé logs have a limited length of about 11 m., a Type 1 bridge never has a free span longer than 11 m. The width and the height of the mainbeam depend on the free span and loading, and as the diameter of the log is limited to about 1.20-1.50 m., the size of the mainbeam is limited to about 0.20x1.00 m.

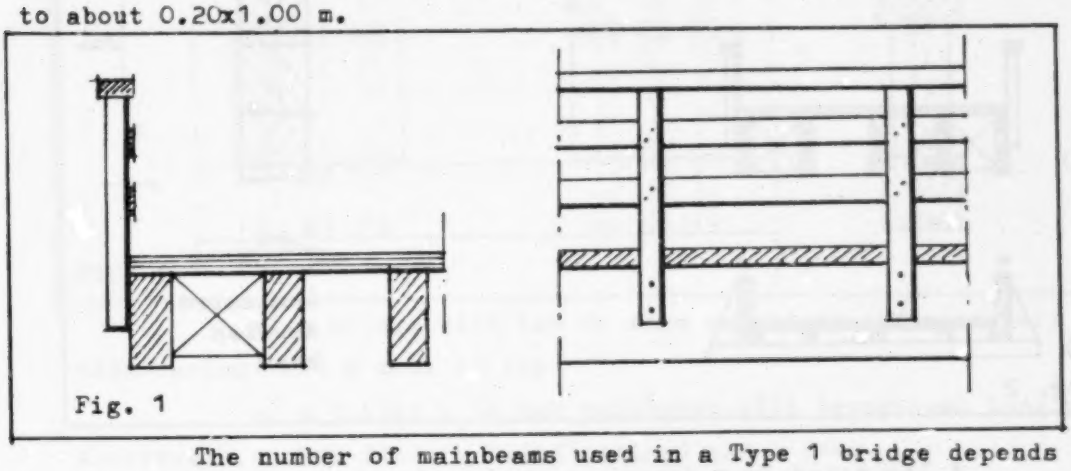


Fig. 1

The number of mainbeams used in a Type 1 bridge depends on the width of the bridge and the maximum deckplank span, which is about 0.70-0.90 m. To prevent the beams from turning over and buckling, a fork support is constructed at the abutments and the beams get cross-frames in the middle of the bridge. If possible, the wind forces are taken over the Y-axis of the beam. If not, a windbracing has to be constructed.

B - Type 2

By a Type 2 bridge we mean a bridge in which the mainbeams are laminated by steel pin dowels (bars). It is possible to differentiate between three main principle cross sections:

a) a bridge with two mainbeams, crossbeams and deck-stiffeners (if necessary a windbracing) and deck on top.

b) a bridge with two or more mainbeams (if necessary a windbracing) and deck on top.

c) a bridge with two mainbeams,with crossbeams hanging underneath,deckstiffeners (windbracing) and a deck.

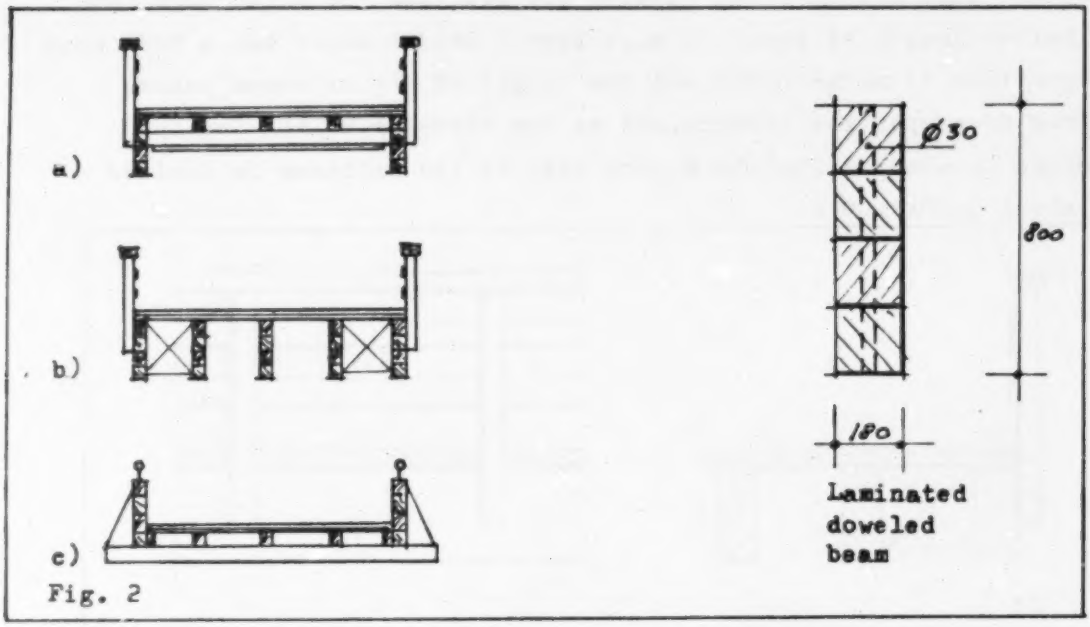


Fig. 2

A laminated beam is composed out of separate massive beams which are connected by steel plate joints lengthwise and piled up vertically.After this process,the total is put under pressure and bowed in the right curve.Next,steel pin dowels are pressed in predrilled holes.In order to keep the layers together, a bolt is inserted at every two meters.Theoretically,enormous beams with enormous spans can be constructed by this method. But when production facilities as well as technical and economical possibilities are taken into consideration,one is bound to be limited.Consequently,for pedestrian bridges the maximum free span applicable is about 25 m. and for traffic bridges an optimum has to be figured out per case .

The turnover and buckling stability in the above mentioned cross sections are guaranteed by:

a) a fork support at the abutments.The crossbeam-mainbeam-windbracing connection all over the span.

b) a fork support at the abutments and crossframes all over the span.

c) cross frames at the abutments and all over the span.

C - Type 3

In this case the mainbeam of the bridge is a "vierendeel" beam.Two main principle cross sections of the bridge are possible:

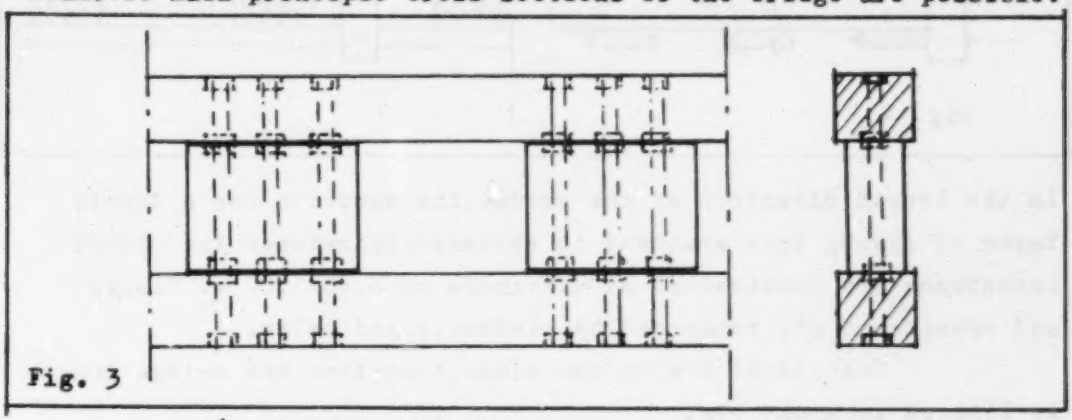


Fig. 3

a) a bridge with two or more mainbeams (if necessary a windbracing) and a deck on top.

b) a bridge with two mainbeams,with crossbeams hanging underneath,deckstiffeners (windbracing) and a deck.

A "vierendeel" beam is composed out of a heavy upper and lower girder,joined by steel plates lengthwise,between which massive blocks are fastened with steel pin dowels,ringdowels and bolts at certain distances from each other.

In case of large spans and high loadings,the beam is constructed with three horizontal layers.For this bridge type too, the largest profitable span is about 25 m. for pedestrian bridges.

It must be mentioned that this type is not very favoured in case of traffic bridges.The "vierendeel" beam does not allow very high shear forces which always occur in traffic bridges.

The turnover and buckling stability measures are similar to the ones described in Type 2 bridges.

D - Type 4

In case of a Type 4 bridge,the main construction is formed by a two dimensional construction,a plate,a sandwich construction.

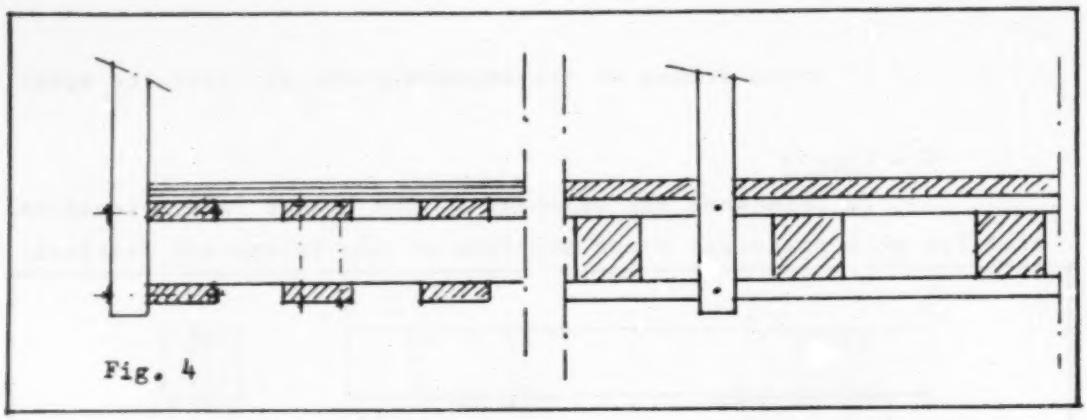


Fig. 4

In the length direction of the bridge, the sandwich has a double layer of planks from abutment to abutment. In between the planks crossbeams are constructed at distances of 0.80-1.00 m. Planks and crossbeams are connected by pindowels and bolts.

The planks are in one piece, therefore the bridge length is limited to about 11m.

Strongly curved sandwich panels can be realized with this type of construction. It is preferably used in pedestrian bridges.

No special stability measures have to be taken.

E - Type 5

In case of a Type 5 bridge, the main construction is formed by 2 or 3 pin arches.

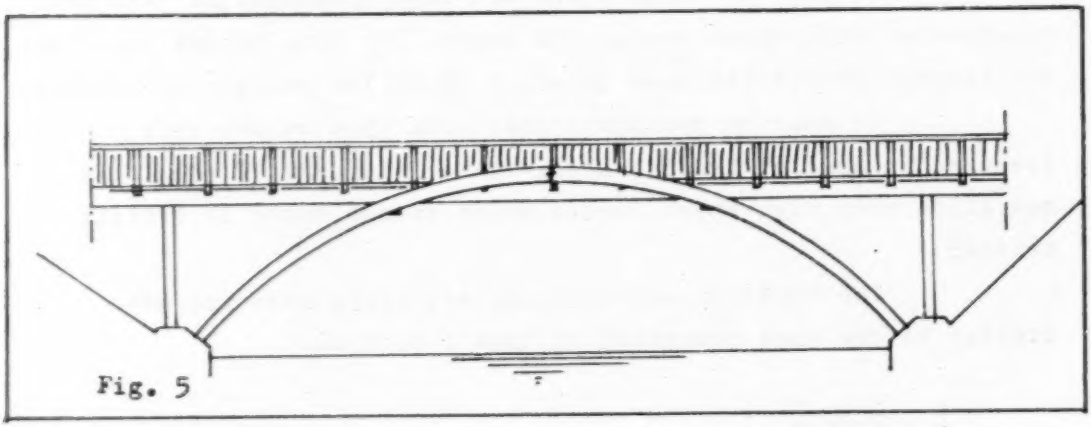


Fig. 5

This type of construction is generally applied to free spans of about 25 m. and more.

The arches are laminated and the separate laminates are joined by steel pin dowels and bolts.

As the arch has a considerably small radius, the laminates have to be thin (60-70 mm.) and therefore numerous (10-15), depending on the span. This makes the production more complicated.

In between the arches rigid crossframes are fixed on which bridge sections of either Type 1 or Type 2 are mounted. The buckling and turnover stability of the arches can be guaranteed by a rigid bridge deck or by a bracing between the arches.

In case of a Type 5 bridge, special attention should be paid to the construction of the foundations. The arches generate forces on the abutments with a horizontal component. To carry this component, heavy pile foundations are often required. The problem is less at sites with a rocky underground.

Special measures should be taken to limit the deflection of the abutments too. The 2 and 3 pin arch can be applied to pedestrian and traffic bridges.

As far as the usage of timber is concerned, the arch is a very economical construction. Large free spans can be realized. The width to span ratio should not be less than 1 to 10, otherwise the turnover stability can become problematic.

F - Type 6

By a Type 6 bridge we mean a bridge in which the main construction is formed by truss girders.

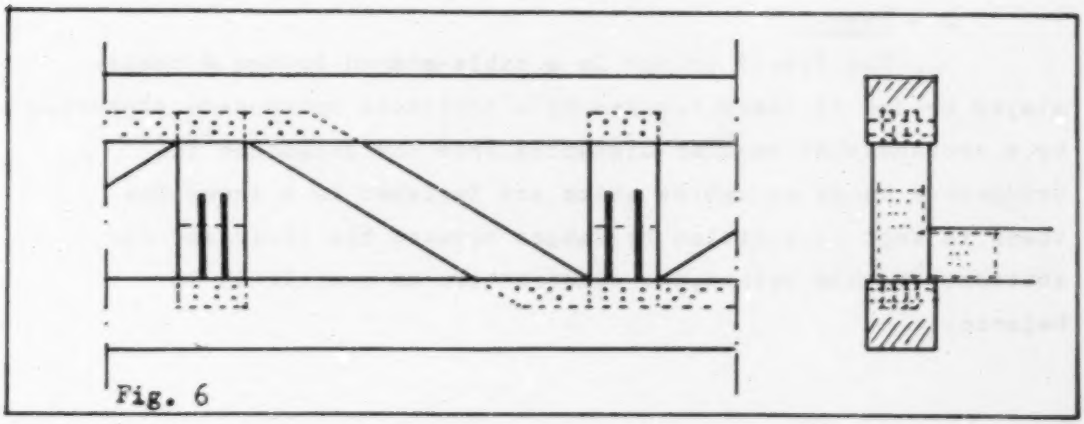


Fig. 6

Two main principle cross sections can be differentiated:

a) a bridge with two or more main girders (if necessary a windbracing) a deck on top.

b) a bridge with two main girders with inbetween or underneath hanging crossbeams,deckstiffeners (windbracing) and a deck.

The truss girder is composed out of a heavy massive upper and lower beam,lengthwise furnished with steel plate joints every ca. 8 m.In the upper and lower beam,cuts are made in which the fingers of the massive diagonals and verticals fit.The finger joint is finished by steel pin dowels in the direction perpendicular to the truss.

The buckling and turnover stability is guaranteed by a rigid steel plate connection between the crossbeam and the vertical of the truss.

The truss girder gives the possibility of spans from 6 to 60 m.The largest realized by Groot is 36 m. With little extra trouble spans up to 60 m. can be made.

In case of large spans,the truss girder has to be so high that a bridge with a roof can be made out of it easily by hanging the deck underneath and by putting a roof construction on top of the truss.

The closed truss girder bridges are frequently seen in West Germany and Switzerland.

The truss construction can be applied to pedestrian bridges as well as traffic bridges.

G - Type 7

The Type 7 bridge is a cable-stayed bridge.A cable-stayed bridge is characterized by a continous bridgedeck supported by a crossbeam at regular distances.From the crossbeam the bridgedeck hangs on cables which are fastened to a tower.The tower is kept in position by cables between the tower and end abutment.By this method,the construction as a whole is in balance.

This type of construction allows free spans from about 20 m. to at least 100m. (in timber).The largest span realized by Groot is about 55 m.

Two main configurations are usual:

a) with one tower,at one side of the main span.

b) with two towers,a tower at either side of the main span.

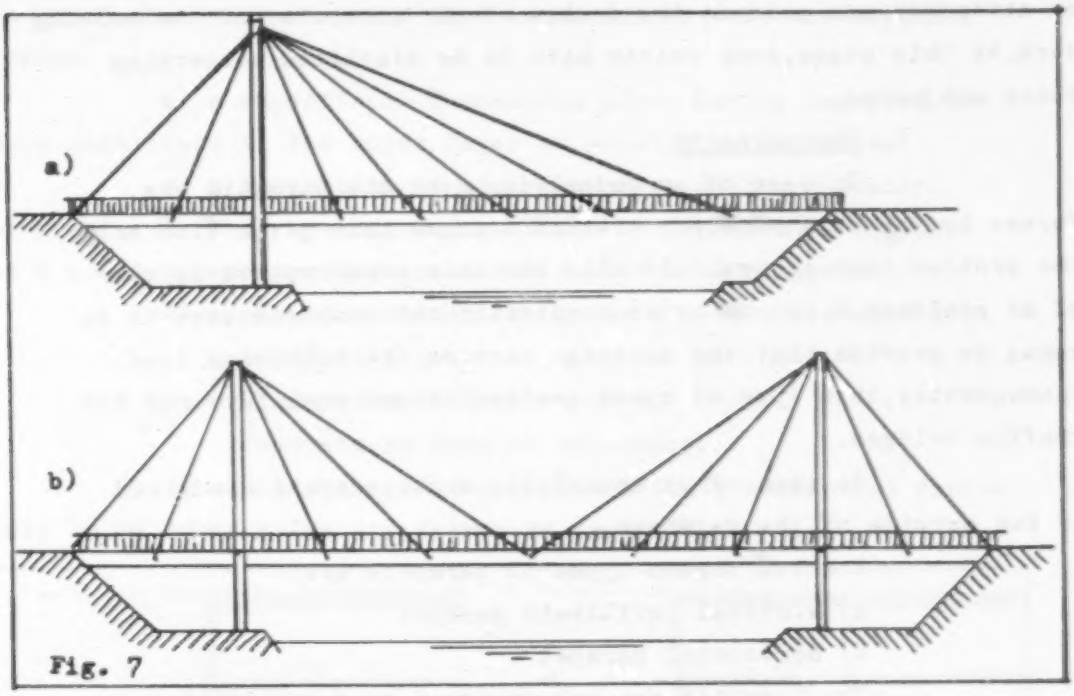


Fig. 7

The bridgedeck is usually designed as a Type 2 bridge of cross section a) .

The towers are manufactured out of a massive piece of Azobé or Basralocus.If the dimensions of the tower are too large to use massive pieces,the tower is laminated like a Type 2 beam. The cables and the crossbeams on which the bridgedeck rests are designed in steel and are mostly galvanized and coated with special protective paint.

Special attention has to be paid to the end abutments: high vertical upward forces are generated at the places where the cables are fixed to the concrete end abutments.

The wind forces on the bridge are carried by a wind-bracing inside the bridge continuing from end abutment to end abutment.

As soon as the free span exceeds 50 m.,an extra feature is apparent: the dynamical behaviour of the bridge.Special attention has to be paid to the feature of "flutter",describing a swing of the bridgedeck as a result of horizontal wind forces.

H - It was mentioned that while describing the seven types, no attention was paid to the design of the parapets and the walking deck.At this stage,some points have to be clarified concerning these subjects:

1. The parapets

In case of an underlying deck,the parapets are formed by the mainbeams.For traffic bridges,this gives rise to the problem that the vehicle hits the main construction in case of an accident.A lot of extra constructional measures have to be taken to provide that the mainbeam carries the collision load. Consequently,this type of cross section is not much favoured for traffic bridges.

In case of an upperlying deck,parapets are fixed to the outside of the mainbeam.

The two common types of parapets are:

a) vertical infillrail parapet

b) horizontal parapet

The parapets are not designed to carry collision loads.In case of traffic bridges,a wheelkerb is fixed on the deck to keep the vehicle in the right track.

2. The walking deck

The deckplanks are manufactured with an anti-skid profile.

If necessary,the deck is made waterproof with tongue and grooved planks with a rubber profile in the grooves.

The size of the planks largely depends on the loadings on the bridge but is minimal 40 mm. for practical reasons (i.e. to prevent the torsion of the planks).

I - Foundations

It is possible to mention four main types of common foundations.The type of foundation that has to be chosen depends on loads and soil conditions.

a) a superficial foundation.The solid underground is directly underneath the surface.A timber plate or a concrete slab on which the bridge is laid down is enough to take the existing forces.

b) a superficial foundation after having improved the soil conditions in the upper layer of about 1 m. maximally.

c) a foundation of concrete rings with a diameter of about 2 m. They are dug in or driven in for about a distance of 4 m. If necessary,they are later filled with concrete.

d) a pile foundation.The materials that are used are:

- Azobé,till about 11 m.
- Basralocus,till about 22 m.
- Concrete,as long as necessary.

The piles are driven in the soil.If horizontal forces have to be taken,piles are driven at an angle.

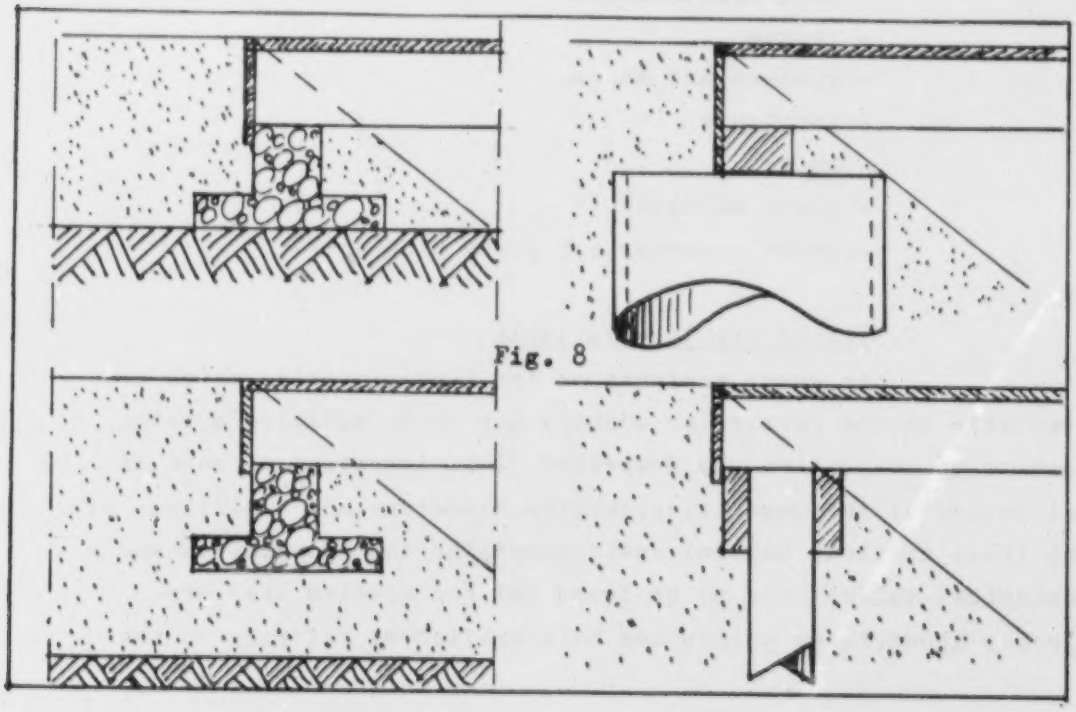


Fig. 8

III. TIMBER BRIDGE CONSTRUCTIONS FOR DEVELOPING COUNTRIES

At this point,furnished with the knowledge of the existing constructions,we will try to place ourselves within the conditions of a developing country and try to find out what the most suitable solutions can be.Before starting to look for solutions,a very thorough investigation and analysis will have to be made to get a complete picture of the local circumstances.A number of points of consideration are mentioned below which can help to form this picture.

A - Checklist for field research

1. Demand

It is very important to find out and define what exactly the needs of the country are.An exact and extensive description of the demand has to be made because timber as a material offers a wide range of possibilities.It is possible to count the following timber products in a list written at random:

- bridges
- roof constructions
- houses
- windows and doors
- furniture
- ships
- plate material
- rests - energy for power plants (?)

2. Timber species available

An exact analysis of the timber species which are available in the particular country has to be made.The species have to be identified and described.It is important to make an estimation of the quantities,lengths,diameters and qualities of the trees in their natural environment.The characteristics and mechanical values have to be found out.For species that are already known,these points can be clarified by refering to the

existing literature.Unknown types have to be classified by tests. Further,their durability classes have to be identified.

3. Location

A geographical description of the country has to be made with particular emphasis on the location of different timber species.It is also important to define the location of the woods in relation with the roads,rivers,seas etc.

4. Market

The places where the products are needed should also be described geographically.

5. Climate

The climate and in particular the temperature and moisture content of the air all over the year must be noted.

6. Soil conditions

The conditions under the ground must be well known in order to design the relevant foundations.

7.Biological and chemical conditions

Research must be conducted to find out about the existing insects,fungi and bacterias as well as acids and bases.

8. Demography,experience and education

In which part of the country does the potential labour force live? While trying to answer this question,one must also try to find out about the amount of knowledge or experience of the local inhabitants concerning timber products.

Are there any foreign companies or consultants who can have any possible impact or can cooperate?

Is there any form of education (i.e. technical schools) which can be useful in training the people on this particular subject?

9. Infrastructure

The existing infrastructure of the country has to be analyzed extensively.In what condition are the roads,the canals, the bridges etc. and what use can one make of the seas and rivers? If necessary,means of improving the infrastructure have to be figured out.

10. Transportation

What are the existing means of transportation and what are the possible means of transportation?

11. Equipment

The equipment that is available should be noted in detail.Such as:

- sawing mills
- trucks and bulldozers
- cranes and driving equipment
- ships
- tools such as chain saws,drills etc.

12. Other materials

Are other construction materials such as concrete, steel,plastics etc. available? How much do they cost?

As soon as this analysis is completed,we can start developing a realization model for timber bridge building in the particular developing country.

B - Preliminary design requirements

1. Standards

Every country in the western world has its own standards system according to which a construction in general and a bridge in particular has to be designed.

In the Netherlands,the standards system is the NEN,

in England the BS, in West Germany the DIN.

If no standards are available in a developing country, we could use one of the above, e.g. the DIN.

2. The DIN

While designing timber bridges the following DIN standards have to applied:

- DIN 1052 Part 1. Timber constructions. Calculations and realization.
- DIN 1052 Part 2. Timber constructions. Regulations concerning doweled joints.
- DIN 1054 Soil conditions.
- DIN 1072 Bridge loads.
- DIN 1074 Timber bridges. Calculations and realization.

These are the most important standards. Others which are of less importance are:

DIN 1080, DIN 4017, DIN 4074, DIN 18137, DIN 68705 and DIN 68800.

3. Loads

DIN 1072 gives the loads on traffi and pedestrian bridges.

Loads are classified as follows:

a) Main loads, that are:
   - permanent loads = dead load
   - traffic loads = live load
   - loads generated by the shrinking and swelling of the timber
   - loads generated by the deflection of abutments

b) Additional loads, that are:
   - wind loads
   - snow loads
   - parapet load
   - loads generated by changing soil conditions

c) Special loads, that are:
- collision loads

The main loads form load case H. The additional loads form load case Z. Main loads plus additional loads form load case HZ. The allowable stresses are increased by 15% in load case HZ. The construction has to be designed according to the heaviest load combination.

4. Free profile

For bridges over roads (fly-overs) as well as for bridges over water, it is important to define the required free profile underneath the bridge. Standard free profiles are only defined for bridges over roads and railways.

5. Mechanical characteristics

Mechanical characteristics are standardized for quite a lot of timber species. A lot of literature exists covering this subject. But if one comes across an unknown type of timber, tests will have to be made to find out the allowable stresses and modulus of elasticity.

C - Design of the superstructure

After having formulated the:
- total length
- free span(s)
- width
- loads
- soil conditions

we can start designing.

As we have already seen in the description of the seven bridge types, we can differentiate two main principles of the cross section:

a) bridges with upperlying walking deck
b) bridges with underhanging walking deck

We can say that,in principle all the possible bridge types can be constructed in developing countries.Nevertheless, we have seen that some bridge types are more sensitive than others:

- in case of an underhanging walking deck,the mainbeam is very sensitive for collision.
- the Type 3 bridge is not very suitable for vehicle loads.
- the Type 4 bridge idem.
- the Type 5 bridge requires foundations of very high quality.
- our experience in Indonesia showed that developing countries are more in need of good,heavy traffic bridges.

If we take the previous points in consideration,we will have to conclude that the following types of construction are most applicable in the particular case of a developing country:

- Type 1 - with upperlying deck
- Type 2 - idem
- Type 6 - idem
- Type 7 - idem

(See Page 18)

As far as the foundations are concerned,all the four mentioned alternatives are applicable (See Part D).

If enough knowledge and experience concerning foundations is present,Type 5,the 2 and 3 pin arch can also be applicable.

Design of the different bridge components

1. The deck

In general,the deck is divided into a top layer which wears out by intensive usage and a load carrying layer.The protective and carrying function can either be combined in one layer or be split up by using two separate layers.The top layer should be resistant to wearing out,smooth,not slippery and replacable.

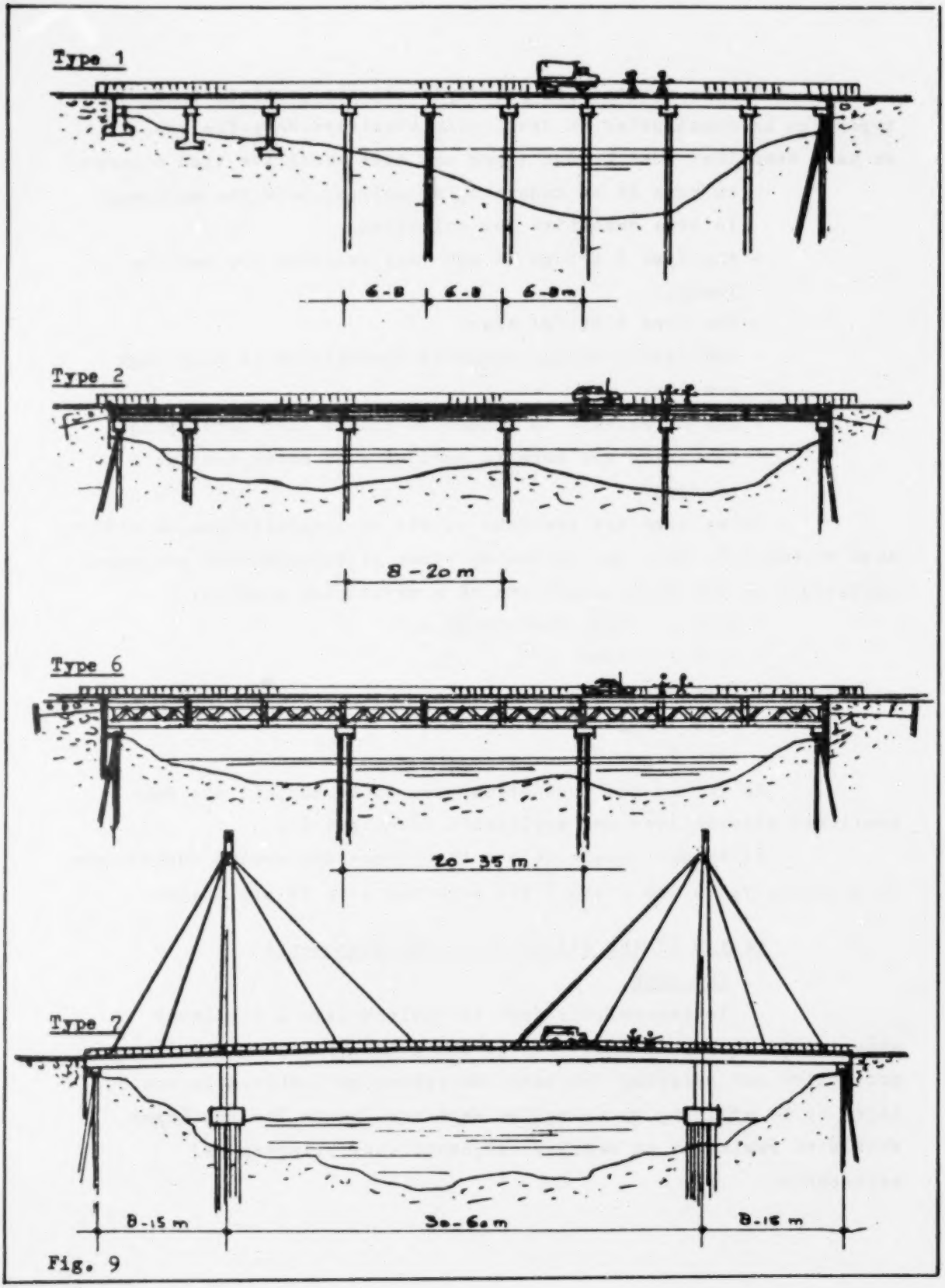


Fig. 9

Possible solutions are:

a) Deckplanks of hardwood.Integration of protective and carrying functions.

b) Top layer of hardwood.Separate carrying layer of the same or another type of wood.

c) Top layer of epoxy or tar.Carrying layer of timber.

A top layer can never be considered as a load carrier.

The load carrier has to be strong and stiff enough to carry the vertical loads.By constructing this layer as a two dimensional plate,it is able to carry horizontal loads generated by wind and stability requirements.

2. Deckstiffener

The function of the deckstiffener is to reduce the span of the deckplanks to about 0.70-1.00 m.

The deckstiffener only takes vertical loads.

3. Crossbeams - crossframes

Crossbeams have the following functions:

a) carrying the vertical load and passing it on to the mainbeams.

b) being part of the horizontal bracing for carrying horizontal forces.

c) being part of the crossframe to prevent the mainbeam from buckling and turning over.

4. Windbracing

If the span of the mainbeam is long and the wind forces high,the last cannot be taken anymore over the Y-axis of the mainbeam. In this case a windbracing has to be designed.Most usual is to construct diagonal planks over the crossbeams.Mainbeams,crossbeams and diagonals together form a horizontal truss girder to take windloads and stability loads.

5. Mainbeam

For the mainbeam,we are left with the following alternatives:

- massive beam
- laminated beam
- truss girder
- and in some cases,the 2 and 3 pin arch

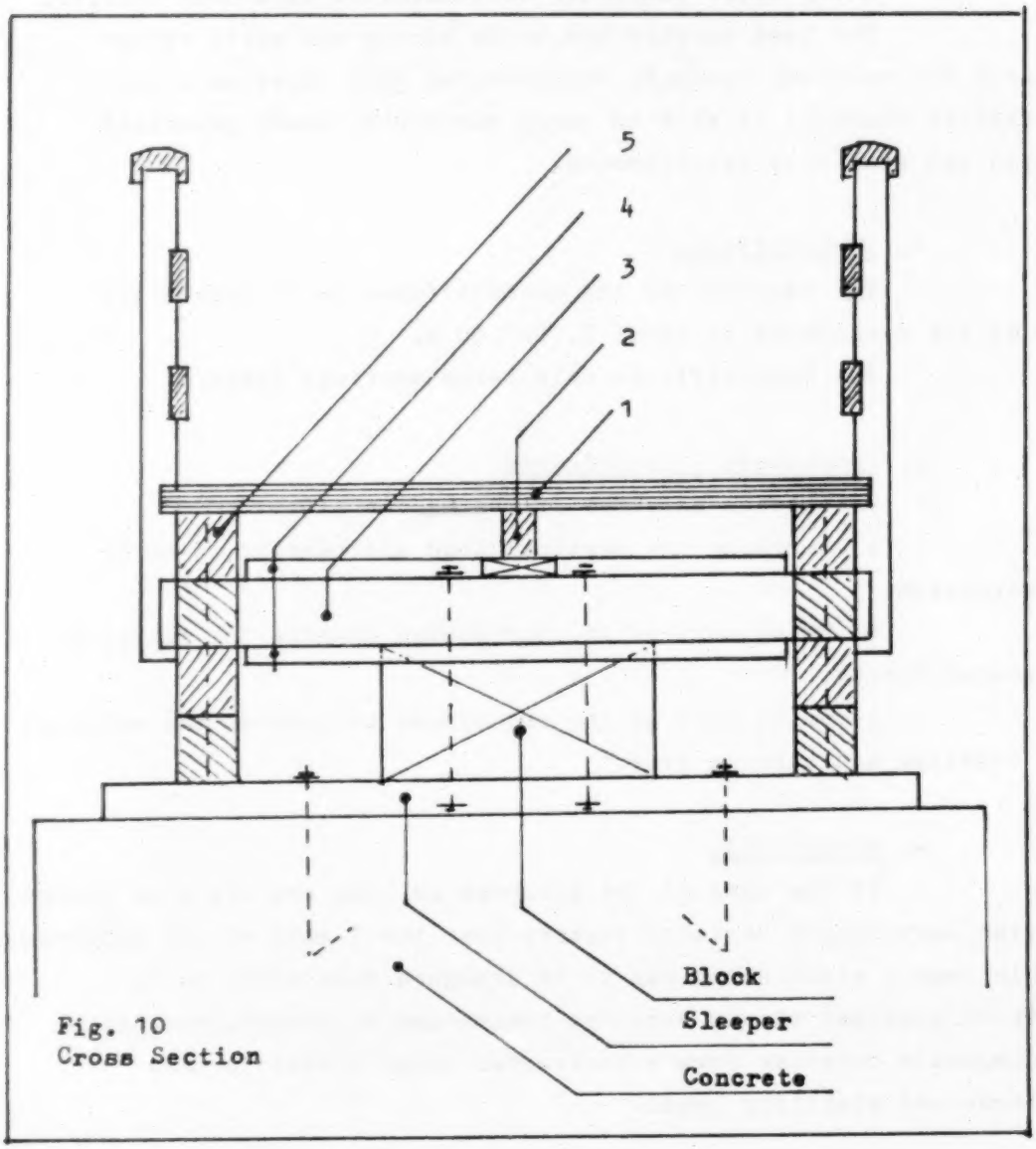


Fig. 10
Cross Section

D - Design of foundations and abutments

In developing countries all four alternative foundation principles that we have seen previously can be applied:

a) superficial foundation

b) superficial foundation after soil improvement

c) concrete ring foundation

d) pile foundation

Abutments

The research that was done in Indonesia showed that the construction of foundations in general and of abutments in particular was poor in quality.Because of this reason,in several cases the bridge had collapsed.It is therefore important to pay special attention to the following items concerning abutments which generally form the connection between land and bridge:

a) they have to stabilize the soil at either end of the bridge

b) they must carry the soil pressure

c) they must be able to carry the vehicle live load acting on the soil at either end of the bridge

d) they have to give stability to the superstructure of the bridge

e) they must be able to carry horizontal and vertical loads acting on the bridge superstructure

f) they have to carry the horizontal loads out of water pressure and floating material

g) they have to protect the soil,the bridge and the foundation against erosion caused by the water coming from the river.

Abutments and foundations mostly form an integrated construction.

A timber construction of the abutment which is often used,consists of a "sheet piling chest".The wings are connected by steel cables.The front side of the chest is kept in position

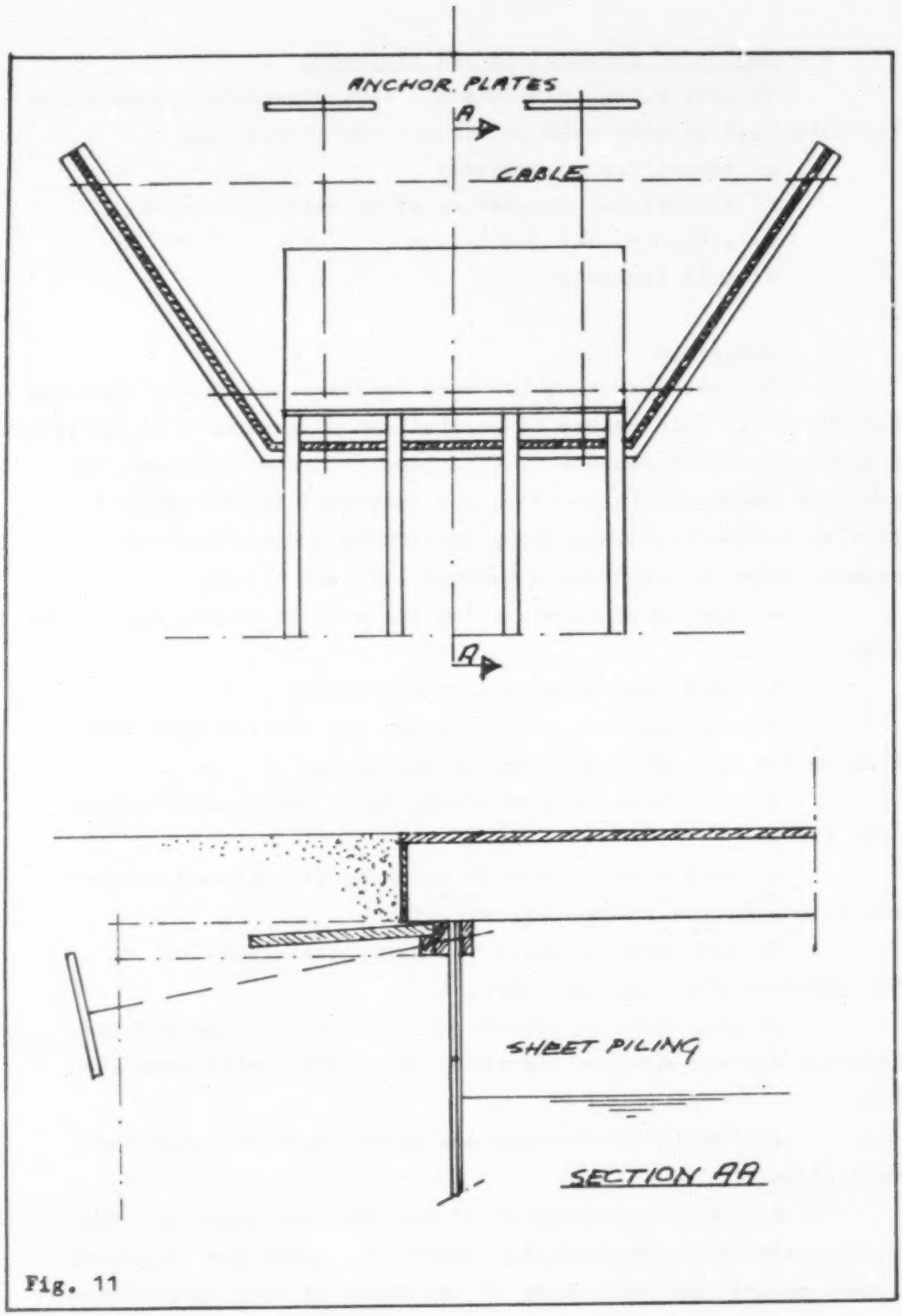


Fig. 11

by anchor plates.The vertical live loads are spread by a horizontal plate at one end supported by the sheet piling.By this method,the sinking of the soil and therefore of the roads directly at either end of the bridge,is prevented.

Another regularly used alternative solution:

The bridge is extended deeper in the soil.As a negative result,the free span of the bridge is elongated.On the contrary, no sheet piling is required,only the shore of the river has to be reinforced.To prevent the sinking of the soil directly next to the bridge,a horizontal plate is required.

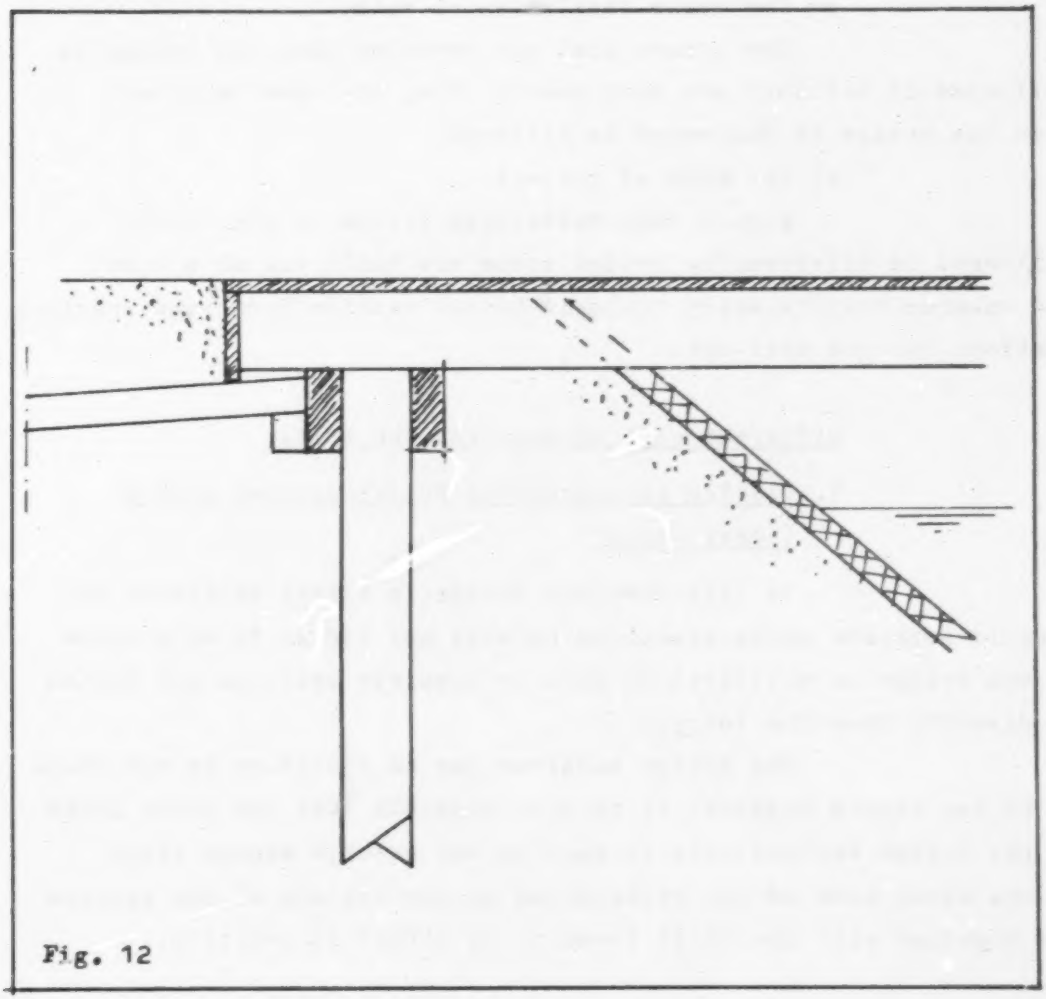


Fig. 12

E - Erection plans concerning superstructures

The bridge can be delivered on site in two ways:

1. completely prefabricated in one or more sections
2. in separate parts,in kit-form

The way of delivery depends on the following factors:

a) Infastructure.

What are the means of access to the site?

b) Transportation facilities.

c) Sizes of the bridge sections.

d) The crane facilities on site.

The cranes that are required when the bridge is delivered in sections are much heavier than the ones required when the bridge is delivered in kit-form.

e) The kind of project.

e.g. a long multi-span bridge is preferably delivered in kit-form.The bridge spans are built one at a time and onwards.That is,every finished bridge section forms the erection platform for the next one.

Different ways of erecting the bridge

1. Lifting in a complete bridge section with a (heavy) crane

In this case,the bridge is either delivered on site in separate parts,assembled on site and lifted in as a whole or the bridge is delivered on site in complete sections and lifted in directly from the lorry.

The bridge sections can be picked up by one crane or by two cranes together.It is also possible that one crane picks up the bridge section,puts it half in the water,a second crane on the other side of the river picks up the one end of the section and together with the first crane it is lifted in position.

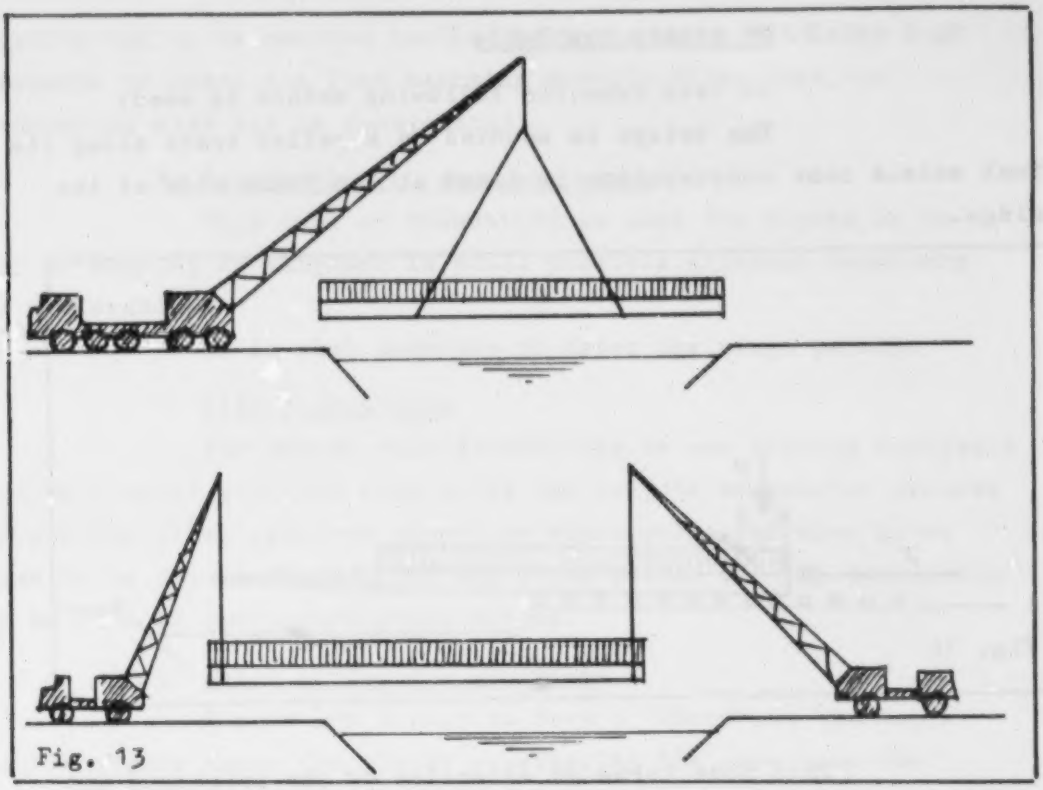


Fig. 13

2. Lifting in of bridge components separately with a crane

The bridge is delivered in kit-form.Mainbeams, crossbeams,deckplanks etc. are in separate parts.First,the mainbeams are lifted in position with a crane.Next,the crossbeams are put in position.Then the windbracing is mounted and the whole process goes on.

The advantage of this erection method is that much smaller cranes can do the job as the weights of the elements that have to be lifted in are much less.

Another advantage is that in this way amendments and adjustments can be made easily on site,to fit the bridge exactly to the abutments.In case of complete bridge sections,alterations are hardly possible.

3. No cranes available

In this case, the following method is used:

The bridge is mounted on a roller track along its final axis. A nose construction is fixed at the front side of the bridge.

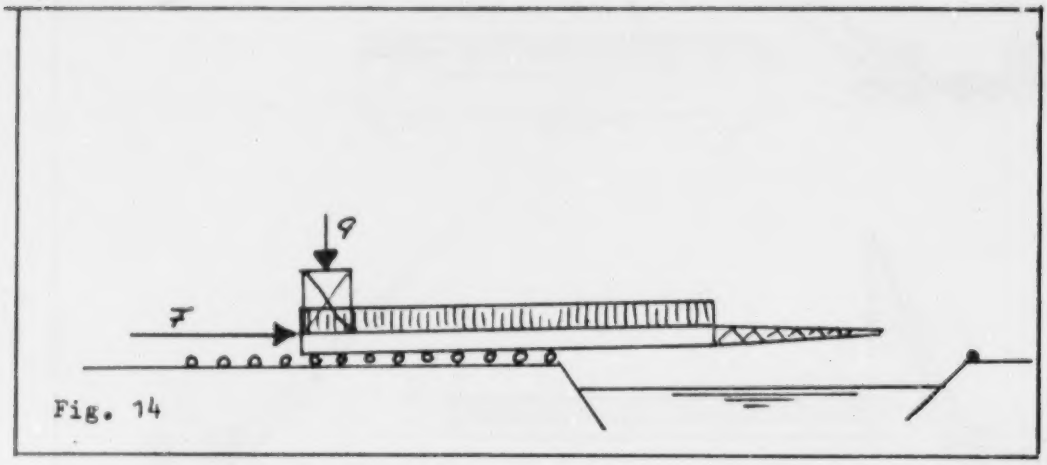


Fig. 14

This nose forms an extension of the mainbeams and points to the opposite side of the river. Its length is about half the length of the bridge beams.

The bridge is rolled over towards the other side of the river. It is kept in balance by a counter weight at the end of the bridge which is opposite to the end where the nose is fixed.

The bridge can be rolled over by manpower or by a hydraulic system. The same kind of method can also be applied to singular bridge beams, instead of a whole bridge section.

F - Erection plans concerning substructures

1. Superficial foundations

This type of foundation can be constructed completely by hand, with manpower.

2. Superficial foundations after soil improvement

This type of foundation can also be constructed totally by manpower. A hole of 1 to 2 m. deep has to be dug. New sand of good

quality has to be carried in.This sand has to be put under high pressure to reach the load carrying density.After that,the foundation slab can be constructed.

3. Foundations on concrete rings

This type of foundation is used for depths up to 4-5 m. Digging by manpower is still possible,although machinery is preferable.

It is also possible to drive the rings partly.

4. Pile foundations

For making pile foundations we use driving equipment and/or a water pump.The long piles can only be driven.The process of driving piles requires expertise,especially when skew piles have to be driven.These piles are often needed for the foundation to be able to carry horizontal forces.

5. Sheet piling for abutments

Planks are driven to form a "chest".At the top a double girder keeps the planks together.At the same time the planks are manufactured with a tongue and groove profile.The "chest" is kept in position by ground-anchor-plates which are dug in the ground.

IV. COST CALCULATION OF HARDWOOD BRIDGES

When calculating the cost of the bridge,the following cost components have to be taken into consideration:

1. timber for superstructure
2. steel parts for superstructure
3. other materials for superstructure
4. labour for superstructure
5. timber for substructure
6. steel parts for substructure
7. other materials (such as concrete etc.) for substructure

8. labour for substructure
9. erection substructure
10. erection superstructure
11. transportation
12. cranes
13. driving equipment
14. other machinery
15. engineering
16. overhead

The unit prices have to be calculated per case.

It is possible to make a comparison between the costs of timber bridges and similar bridges in steel or concrete.The following aspects have to be taken into consideration:

Weights

The weights of a hardwood bridge and a steel bridge of the same size and load class are very similar.Consequently,transportation costs and crane costs for installation will be practically the same. The size of foundations will also be quite identical.

On the other hand,a concrete bridge of the same size and load class is a few times heavier in weight.As a result,transportation and crane costs increase with the same ratio.The foundations have to be much heavier too.

Maintenance costs

Constructing bridges out of tropical hardwood such as Azobé, in the northwest of Europe,has the advantage of having minimal maintenance costs.The timber does not require any form of treatment. In tropical countries the problem of maintenance is bigger.Because of the enormous changes of temperature and the moisture content of the air,timber wears out easily.Therefore,elements like parapets have to be treated with protective paints.Deckplanks have to be constructed thicker for the same reason.In general we can say: In order to keep the maintenance costs low,it is absolutely necessary that the detailing of the total construction is done very accurately (e.g. think also of the problem of termites).

Production facilities

It must be mentioned that the cost of the final product is determined to a large extent by the production facilities available.

Costs of basic materials

Another important factor determining the final cost is the cost of basic elements such as timber, steel or concrete. The costs of these materials may vary considerably in different countries.

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.447/11
20 December 1985

ENGLISH

Expert Group Meeting on Timber Construction
Vienna, Austria, 2 - 6 December 1985

HAZARD CLASSES OF TIMBER IN USE *

Prepared by

C. R. FRANCIS **

* The views expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

** Civil Engineer, Auckland, New Zealand.

V.85-37734

CONTENTS

	Page
Hazard Classes of Timber in Use	1
Table I: Two Hazard Classifications	5
Table II	7
References	8
Figure 4	9

HAZARD CLASSES OF TIMBER IN USE

In this paper discussion is limited to biological hazards to timber construction. Temperature chemical and fire damage may be extremely important in some situations, but these are relatively rare and have little relevance to the formulation of a timber preservation standard.

Biological hazards to timber can range from zero as in the interior of an Egyptian tomb or in Antarctica to extreme, where timber may be completely decayed or termite-ridden in a matter of weeks. Between these extremes hazards merge more or less gradually into one or another with few well defined demarcation limits.

The definition of hazards is a necessary prologue to the setting of preservative treatments either of type or degree or both. But here also the degree of protection even with a particular specification and timber species may vary widely due to inevitable variations in the wood, between batches and between preservative chemicals which have been assigned the same nominal efficacy.

The various hazard classes and the various corresponding treatment specification distribution may be depicted as two series of frequency curves where the overlap between a hazard and its corresponding preservative is acceptably small. Thus, a single case e.g. anobium attack might be represented in Fig. 1 by curve H while the corresponding preservative specification is curve P. Protection is gained except in the shaded region where H $>$ P on the intensity axis. If a given percentage, say 1% of pieces is acceptable as being unprotected i.e. subject to attack then the area U remains constant and various possibilities may be explored. In Fig. 2 are shown a lower treatment level with more rigourous process control, with consequent savings in salt cost but more expensive control. Figure 3 shows the effect of wrong hazard definition for the process specified, e.g. mixing in carpenter bees with anobids or lycta. (Carpenter bees, which do not ingest wood are not deterred by biocides.)

The whole range of hazards and corresponding preservation systems might be as Fig. 4. It can be seen that while hazard definition is important, equally so is appropriate preservative specification and the two interact for satisfactory economy.

These concepts will be familiar to structural engineers conversant with reliability based design. Goodman (I) gives a summary of this concept and the associated statistical procedures which could be transferred to the problem of matching hazards and protection.

In preservation codes, hazard definitions follow a fairly regular pattern. Table I gives the detailed descriptions given in the Fijian standard and in the proposed standard currently under discussion for joint adoption by New Zealand and Australia. The required minimum retention levels for a widely used treatment salt are shown. Most other codes follow much the same format with additions for specialised products such as plywood or beehive timber. Comparisons between codes are very difficult. This is partly because similar wordings may describe quite different hazards, as for example, the risk of fungal attack in cool and tropical climates. This is effectively the lateral position of curve H in Fig. 1. The other difficulty is the probability of failure accepted, that is the shaded area in Fig. 1. This is rarely if ever stated, or even accurately described. A suitable prescription for a hazard/preservation combination would be: "This specification will provide 95% survival after 80 years" (the prescription for NZTPA specification C2B for house poles). Even where some attempt is made in this direction it is frequently incorrectly stated. Thus the wording of H5 Table 1 ends up ".... is a critical use requiring additional protection". What the specifier is really after is a lower probability of failure for a given lifetime or a longer life for a given probability of failure, or both. The result of this is more intensive treatment, but this may be achieved by more rigourous quality control rather than by higher retention levels. This point is well illustrated by comparison of the NZTPA specifications C5 for fencing materials and C6 for exterior joinery. The same retention levels are specified e.g. 5.4kg/m^3 for Tanalith NCA, but whereas all species are allowed in C5, only Radiata pine is permitted in C6. There are no penetration requirements in C5 but in C6 complete penetration is required, detailed sampling procedures are specified as are the core analyses of active elements and the allowable tolerance.

A detailed comparison has been made by Hedley (2) of the requirements of the codes of New Zealand, Queensland, New South Wales, Standards Assn. of Australia, Fiji, Japan, USA and UK. This runs to 12 pages of detail.

The differences between code requirements for the same hazard description are sometimes very large, e.g. up to 3 times the retention for anobid/lyctid treatment between New Zealand and Japan. Some of these differences may be due to desire for lower failure probabilities, some to conservatism, but some must also be due to different meanings attached to hazard descriptions.

The writer is aware of only one attempt to numerically classify a decay hazard. This is Scheffer's Climate Decay Hazard Index for wood out of ground contact.

$$I = \frac{1}{30} \sum_{Jan}^{Dec} \left[(T - 35)(D - 3)\right]$$

where: T is mean monthly temperature ^{o}F

D is the mean number of days in the month with 0.01 inch or more of precipitation. The factor 1/30 arbitrarily brings the index into the range 0 - 100 for the USA.

$I < 35$ is low decay hazard

$I = 35 - 65$ is moderate decay hazard

$I > 65$ is high decay hazard

It has later been proposed that 70 is a more practical boundary than 65.

Use of the CDH Index is confined to only one of the six Hazard Classes described in Table 1 but its quotation in specifications for H3 could be a useful means of giving some assurance to the transfer of one country's specifications to another. Unfortunately no similar indices have been developed for ground contact specifications.

There is general agreement between preservation scientists that more uniform and objective preservation standards are required. Hedley in an internal report, described how both New Zealand and Queensland at a recent meeting both came up with similar proposals for standardising evaluation protocols for wood preservatives and subsequent approval for commercial use. But the quality control criteria also need to be standardised in the same way that wood strength statistical criteria are becoming internationally standardised. General agreement on the reliability indices to be used in considerations of hazard/protection diagrams such as Fig. 1 would also be highly desirable.

Proposals such as these are only starting to be discussed. In the meantime immediate action is required for the preparation of treatment standards in numerous widely differing developing countries. These countries differ in climate, in insect species, timber types and species and in construction practices. The cost-benefits of preservation will also vary widely from country to country.

In recommending a preservation code for use in developing countries, it is apparent that there is almost complete absence of objective criteria for guidance. The best we can hope for is that experience and judgement are wisely applied, and that regulations are so framed that as improvements and changes in specifications are warranted, that these applied in a rational manner.

TABLE I

Two Hazard Classifications

NZ - Australia	Fiji
Hazard Class H1. Where timber, including plywood is used out of contact with the ground and in situations which are adequately ventilated and continuously protected from the weather by roofs, external walls or a well maintained paint system. The primary risk to timbers is attack by wood boring beetles such as Anobium and Lyctus. NZTPA Tan NCA 3.2 Kg/m^3	Out of ground contact and continuously protected from the weather. Situations where timber is continuously protected from the weather, adequately ventilated, free of contact with the ground, damp masonry, etc. e. g. furniture timbers, internal panelling, interior framing and roofing timbers. etc. Main Hazards: Drywood termite and pwder post beetle Tan NCA 3.5 Kg/m^3
Hazard Class H 2. As for H 1 but giving protection against termites also. No NZ equivalent. A$1604 and Q'land Tan NCA 4.0 Kg/m^3	
Hazard Class H 3 Where timber including reconstituted wood products may be exposed to the weather but will not be in contact with the ground. NZTPA Tan NCA 5.4 Kg/m^3	2 Out of ground contact NOT continuously protected from the weather. Situations where timber is not in ground contact but is not continuously protected from the weather, or damp masonry in unventilated groundline floors, other damp situations, exposed verandah floors, garden furniture, barge boards etc. Main Hazards: Fungi, drywood termite and powder post beetle. Tan NCA 7 Kg/m^3

Hazard Class H4. Where timber is used in contact with the ground or in fresh water or in other situations favourable to decay. Very severe environments such as horticultural sites constitute a higher hazard (Class H5) which should be used for critical commodities

NZTPA Tan NCA 10.1 Kg/m^3

Hazard Class H5 Where timber is used in contact with ground that because of the climate., soil or other factors presents and extreme decay hazard or where the commodity is a critical use requiring additional protection.

NZTPA Tan NCA 13.5 Kg/m^3

Hazard Class H 6. Where timber is subjected to prolonged immersion in sea water.

NZTPA Tan NCA 24 Kg/m^3 rounds
28 Kg/m^3 sawn and part rounds

3. In ground contact. Situations where timber is in continuous contact with the ground. This end-use category is subdivided into two, based on the acceptable life of different commodities and their relative values.

3A Low risk, low val ue items e.g. fence posts, passion fruit poles etc.

3B High risk, high value items, e.g. house piles, poles for pole frame housing, transmission poles etc.

Main hazards: Fungi, subterranean and drywood termite and powder post beetle.

Tan NCA 18 Kg/m^3

4. Marine uses. Situations where timuer is continually exposed to marine boring organisms e.g. boat and barge external sheathing, marine piles, bracing, ramps, slipways, groynes, sea walls etc.

Main hazard: Molluscan and crustacean marine borers

Tan NCA 48 Kg/m^3

TABLE 2

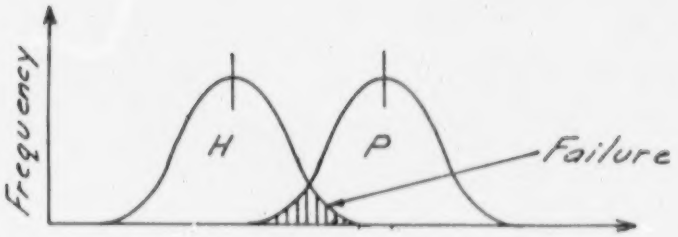
Retention requirements for CCA type 1 Exterior Use, not in contact with the ground.

Country and specification	Retention
New Zealand TPA C5, C6, C6B, C7, C11	5.0 - 5.4
Queensland TUMA H3	8.4
New South Wales TMA) Stds Assn of Australia AS1604/6)	6.0
Fiji FDF2	7.0
Japan JIS A9108	6 - 10.0
USA AWPA C2	6.0
UK BWPA	Process Sec. 2% solution strength

REFERENCES

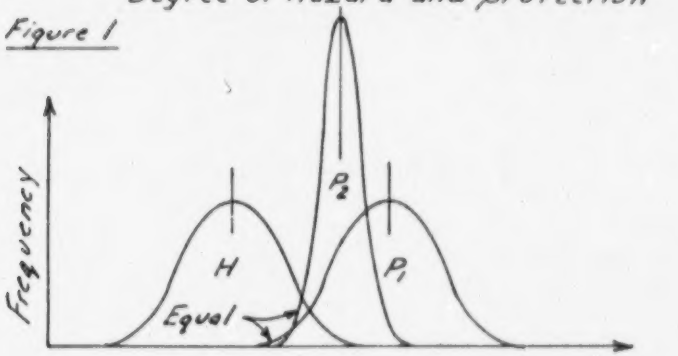
(1). Goodman J.R. 1984 "Reliability-Based Design for Wood Structures" Structural Wood Research ASCE, 345 East 47th St. New York

(2) Hedley M.E. 1984 Timber Preservation Standards in NZ, Australia, Fiji, Japan, USA and United Kingdom. Report to Forest Research Institute Wood Preservation Working Group.



Degree of hazard and protection

Figure 1

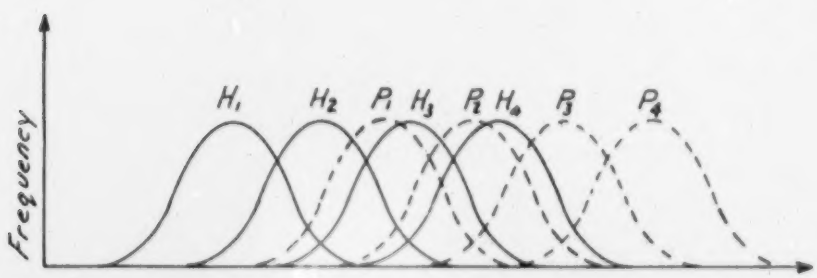


Effect of tight quality control

Figure 2

Poor hazard definition

Figure 3



Complete hazard and protection system

Figure 4